NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20594

Office of Research and Engineering
Safety Studies and Statistical Analysis Division

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A Study on the Effects of Pressure on Aviation Airbag Vent Hole Fraying

A. BACKGROUND

In 2006, the NTSB initiated a safety study to evaluate the efficacy of aviation airbag systems in mitigating occupant injuries in general aviation (GA) accidents. Current aviation airbag systems are mounted in either the lap belt or shoulder harness portions of restraint systems. They are designed to deploy outward from the pilot or occupant when the aircraft decelerates rapidly in the longitudinal direction and reaches a predetermined activation threshold. Once the threshold is met, an inflator assembly mounted near the seatbelt attachment point releases non-heated, inert helium gas to fill the airbag.

The two most common airbag designs were used in this study and are depicted in Figure 1. The airbags have one or two vent holes on the side of the bag that faces away from the occupant. The vent holes affect occupant-to-bag loading because they control the release of gas as the occupant compresses the bag during the impact. The vent holes also gas to escape from the airbag after deployment has occurred.

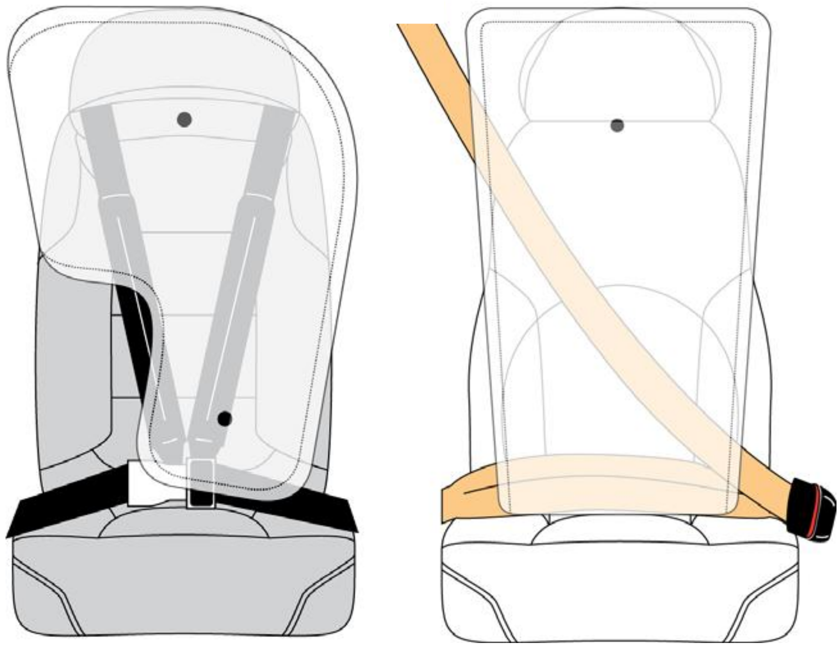


Figure 1. Diagrams showing the approximate shape and vent hole placement of the Cirrus (left) and Cessna (right) airbags when they are deployed. The vent holes are the small black circles on each airbag.

Early in the study, representatives from the airbag manufacturer, AmSafe, suggested that the presence of "squaring" (a square-shaped fraying pattern around the originally circular vent hole) may be indicative of pressure having been applied to an airbag during a crash. As such, during the safety study data collection period NTSB investigators routinely documented the number of frayed threads on airbag vent holes as a potential indicator of the extent to which the airbag had been loaded during the accident.

On August 17-19, 2010, NTSB staff visited the AmSafe manufacturing facility in Phoenix, Arizona to conduct controlled testing to further understand the potential relationship between loading on the airbag and fraying of the airbag vent holes.

B. TEST OBJECTIVE

The objective of the testing was to determine the relationship between airbag pressure and fraying of the vent hole for the two most common GA airbag types (Cessna 172/182/206 and Cirrus SR20/SR22).

C. MATERIALS

Testing employed 12 Cirrus and 9 Cessna production-representative airbags. The airbag fabric is nylon with a silicone coating. Cessna airbags are rectangular, have a volume of 32.5 liters, and have one vent hole on the upper portion of the bag. Cirrus airbags are L-shaped, have a volume of 20.9 liters, and have two vent holes on the upper and lower portions of the bag.[1] The airbags had been sewn to a strip of polyester webbing consistent with the production method but were not folded or encased in a cover as they typically are when installed in the aircraft. The vent holes of all airbags were laser-cut, which is the most common process used by the manufacturer.[2]

D. PROCEDURES AND MEASUREMENTS

As shown in Figure 2, the airbag was strapped down upon a carpeted platform, occupant side down with a gas hose leading to an inflator adjacent to the airbag. Weights, beams, and clamps were used to simulate various loading conditions on the airbag. The four conditions described below were designed to produce different levels of pressure within the airbag during deployment

1. Baseline: No weight applied
2. 45 lbs: One 45-pound weight positioned 1.5 inches above the airbag[3]
3. 135 lbs: Three 45-pound weights positioned 1.5 inches above the airbag

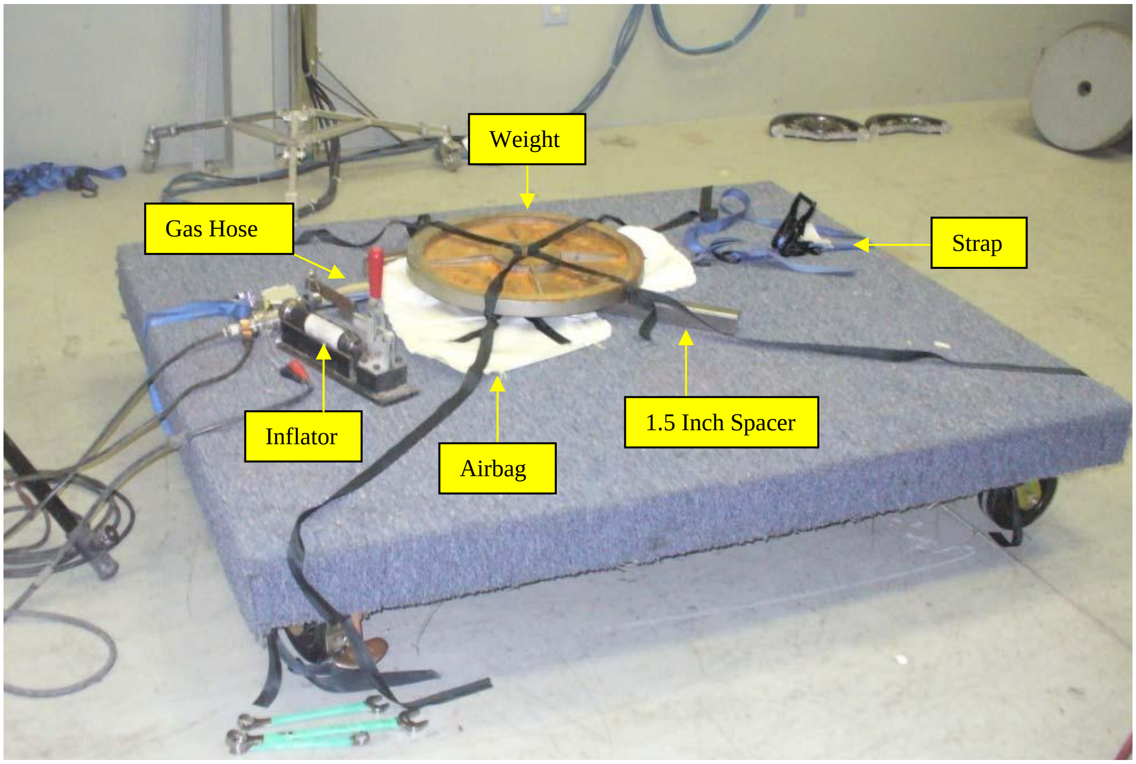
[1] The lower portion of the Cirrus airbag is reinforced with an extra layer of fabric and the lower vent hole is cut through both layers of fabric. Fraying on all three holes was documented during testing and the maximum observed fraying was used in the analysis.

[2] Other methods of producing the vent holes are by heated die or by a hand punch.

[3] Note that this condition was only used for the Cirrus airbags since pilot testing showed that the 45 lbs condition had no effect on fraying of the Cessna vent holes

4. Clamped: One 45-pound weight and a steel beam positioned 1.5 inches above the airbag, with C-clamps holding the steel beam to the platform.

Airbag vent holes were photographed before and after airbag deployment[4], and a high speed video recording was made of each deployment. Pressure was measured using a pressure transducer with a tap that was fed into the airbag. The end of the pressure tap was located around the center-point of the airbag. Pressure was sampled continuously at 1,000 Hz intervals during the deployment; however, only the peak pressure reading was used in the analysis. After airbag deployment, each vent hole was examined using a standard microscope and the number of frayed threads was documented by starting at the most extremely frayed corner and counting inward toward the original circular shape of the vent hole. See Figure 3 for an example of two vent holes that were photographed after deployment, one with very little fraying and one with heavy fraying. For airbags with more than one vent hole, the thread count from the most frayed hole was used.



[4] Three of the 12 Cirrus bags were observed to have a brownish burnt appearance around the vent hole and the outer edges of the airbag Those bags were distributed into different test conditions to avoid a confounding effect between the brown vent holes and the load conditions.

Figure 2. A labeled photograph showing the test set-up for the 45lb load condition.

Figure 3. Example photographs showing vent holes with 2 threads frayed (left) and 9 threads frayed (right). The image on the right depicts two layers of fabric with two overlaid vent holes.

E. RESULTS

The raw data from the pressure measurements are provided in Appendix A and a table showing the peak pressures and vent hole fraying data for each test is provided in Appendix B. A scatterplot, shown in Figure 4, depicts the relationship between peak airbag pressure and the maximum level of vent hole fraying for both Cessna and Cirrus airbags. Across all test conditions, the peak pressure loads for the Cessna airbags were lower than those for the Cirrus airbags, which is consistent with the larger volume of the Cessna airbags.

For Cirrus airbags, there was a fairly clear relationship between peak airbag pressure and vent hole fraying. When the peak pressure was less than 100 kPa, vent hole fraying was typically fairly low; however, when pressure exceeded 100 kPa, vent hole fraying was considerably higher, and in several cases, the characteristic "squaring" shape was observed.

For Cessna airbags, the relationship between peak pressure and vent hole fraying was not as evident, possibly due to the fact that none of the test conditions resulted in peak pressures that exceeded 89 kPa. Six of the nine tests conducted on Cessna airbags resulted in negligible (1 thread or less) fraying. The three tests that were conducted in the Clamped condition resulted in the highest levels of fraying, ranging from 3-17 threads; however, the trial that resulted in the most severe fraying had a peak pressure reading of 56 kPa.

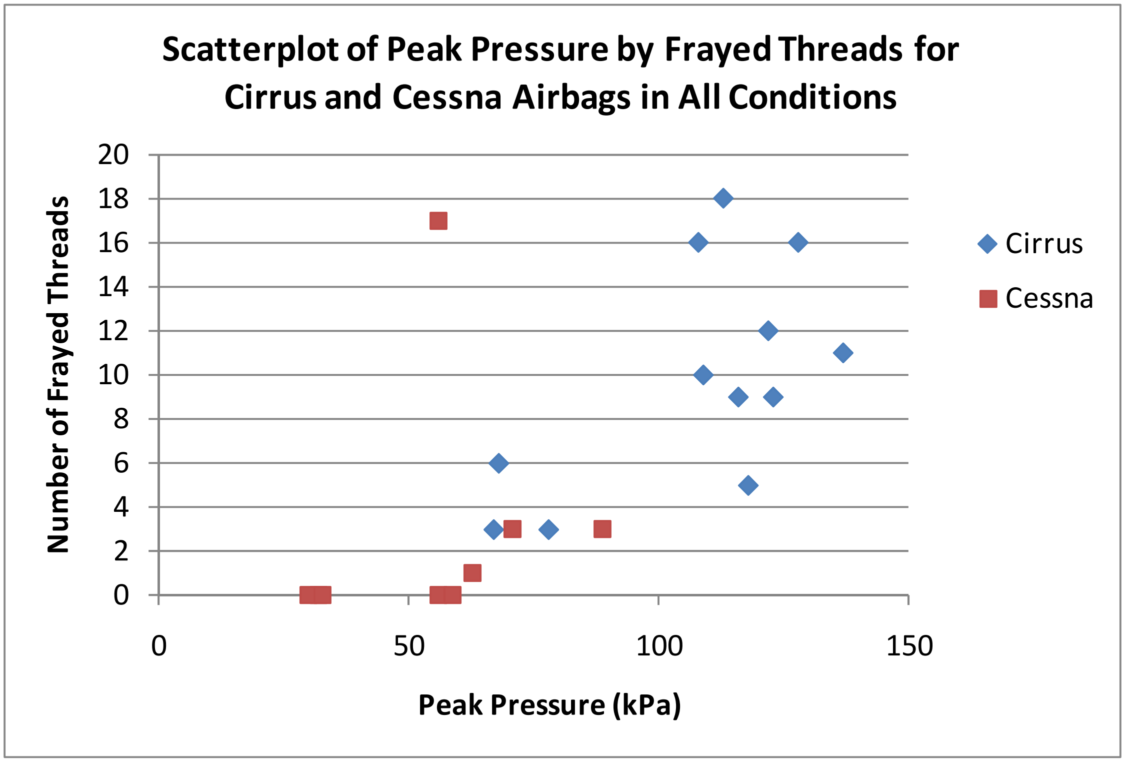


Figure 4. A chart showing the relationship between peak airbag pressure and maximum vent hole fraying for all Cessna and Cirrus deployments observed in the study.

F. DISCUSSION

The objective of the test was to determine the relationship between airbag pressure and fraying of the vent hole for the two most common GA airbag types. Although there was some variability within the test conditions, higher peak pressures were generally associated with more extreme vent hole fraying. Overall, the findings suggest that while the absence of vent hole fraying in a deployed airbag should not be interpreted to mean that no load was applied to the bag, the presence of heavy fraying or "squaring" is likely an indicator that the bag underwent pressure above the pressure that is encountered by simply deploying the airbag without an external load.

There were a few limitations to the study that may limit the generalizeability of the findings. First, the airbag was uncovered and unfolded, which is not consistent with its normal pre-deployment state. Although having the airbags in this condition improved the experimental control over the conditions and facilitated better pre/post measurement of the airbags and vent holes, it also lacked fidelity as compared to normal deployment conditions. Similarly, the fact that the loads applied to the bag came from static weight placement rather than from dynamic forces is also inconsistent with the way loads would typically be applied in an airplane crash. Higher fidelity testing, such as a sled test with an anthropomorphic dummy interacting with the deploying airbag, would have been preferable, but was precluded due to resource limitations.

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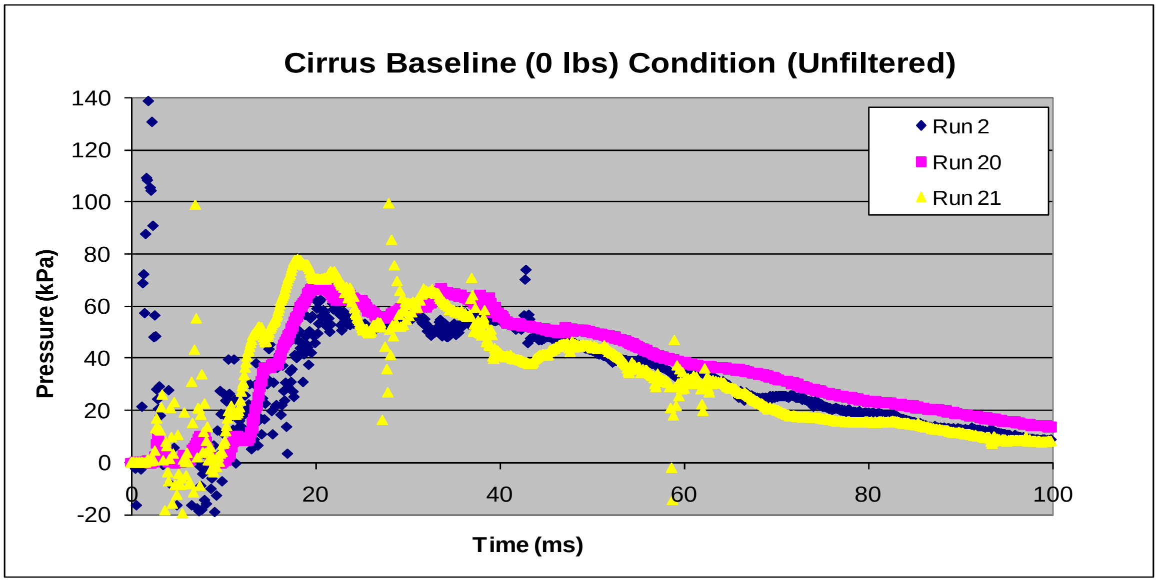
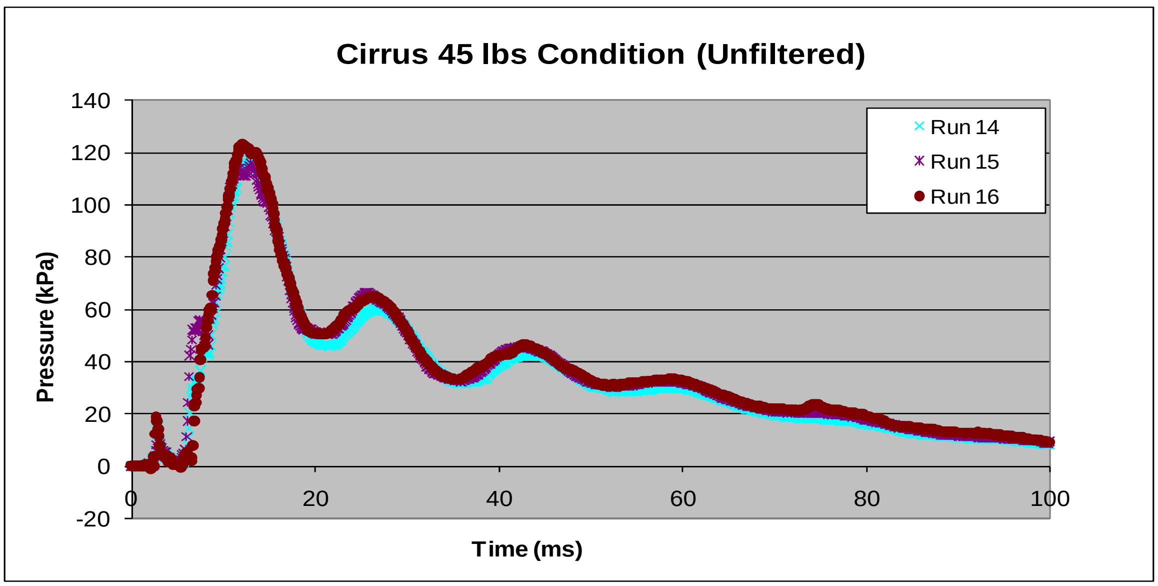
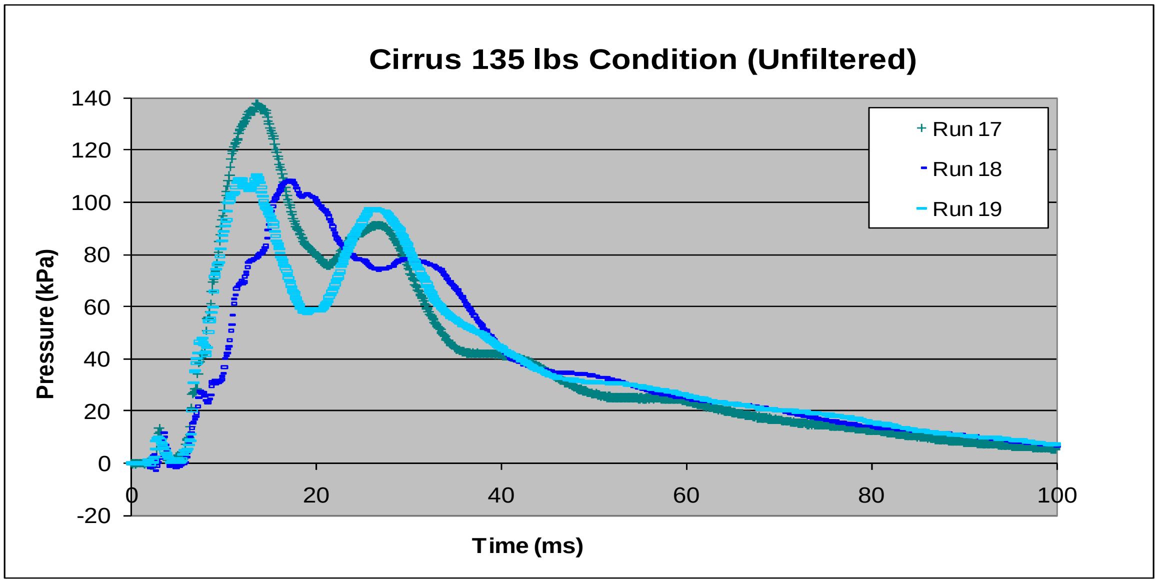
Appendix A.

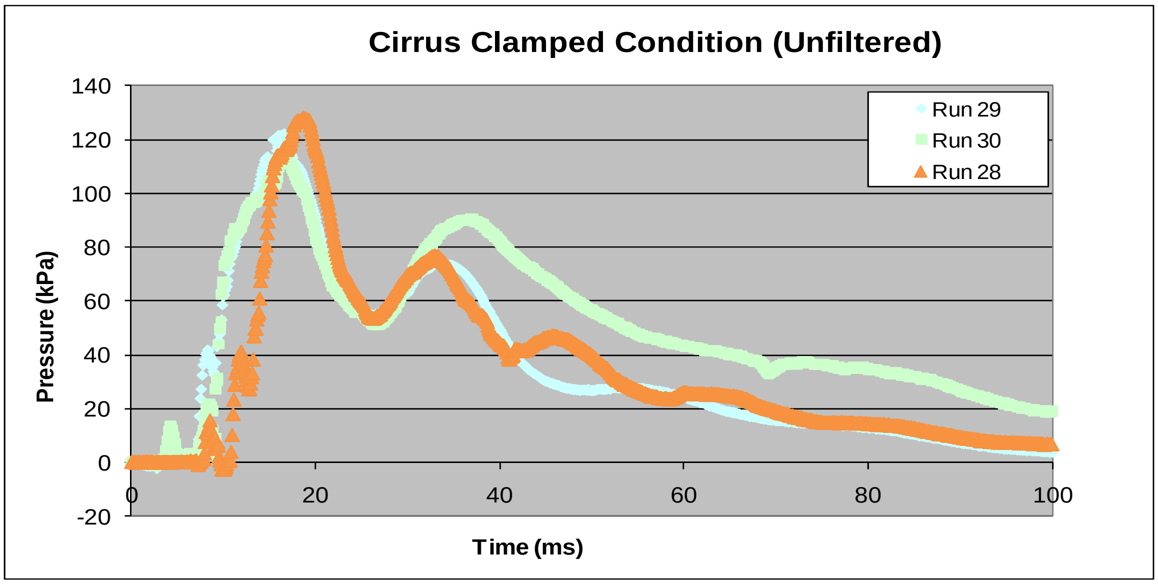
These charts depict the sampled pressure measurements for the first 100 milliseconds of each airbag deployment. The charts are grouped by airbag type and condition. Note that for the first two deployments (Run 1 and Run 2), the pressure tap was located directly adjacent to the inflator. For the remaining deployments, the pressure tap was moved to be centrally located in each airbag.

Cirrus Deployments

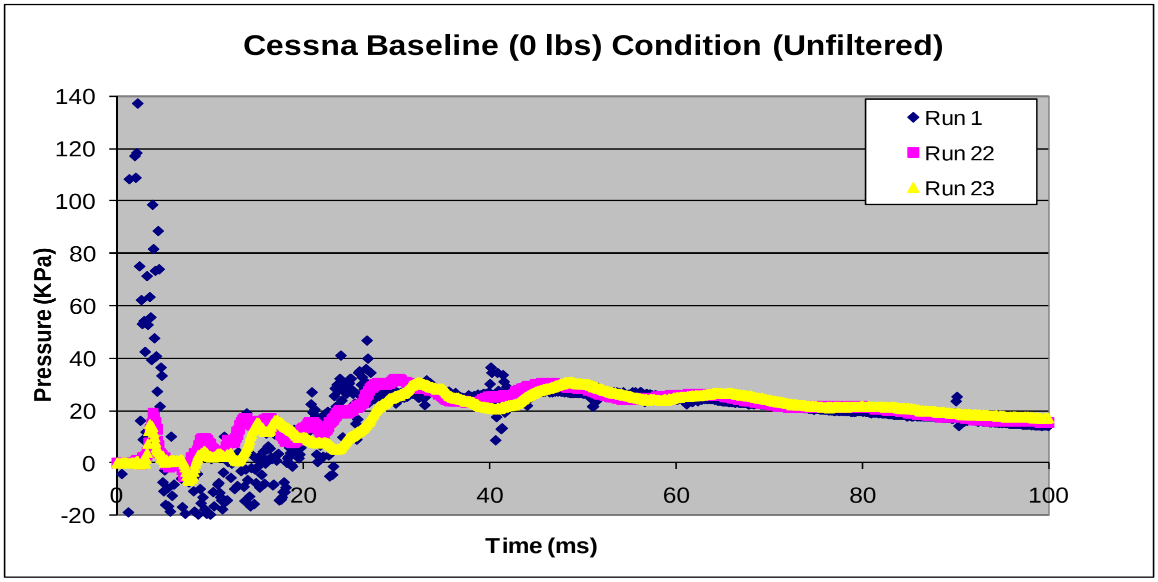


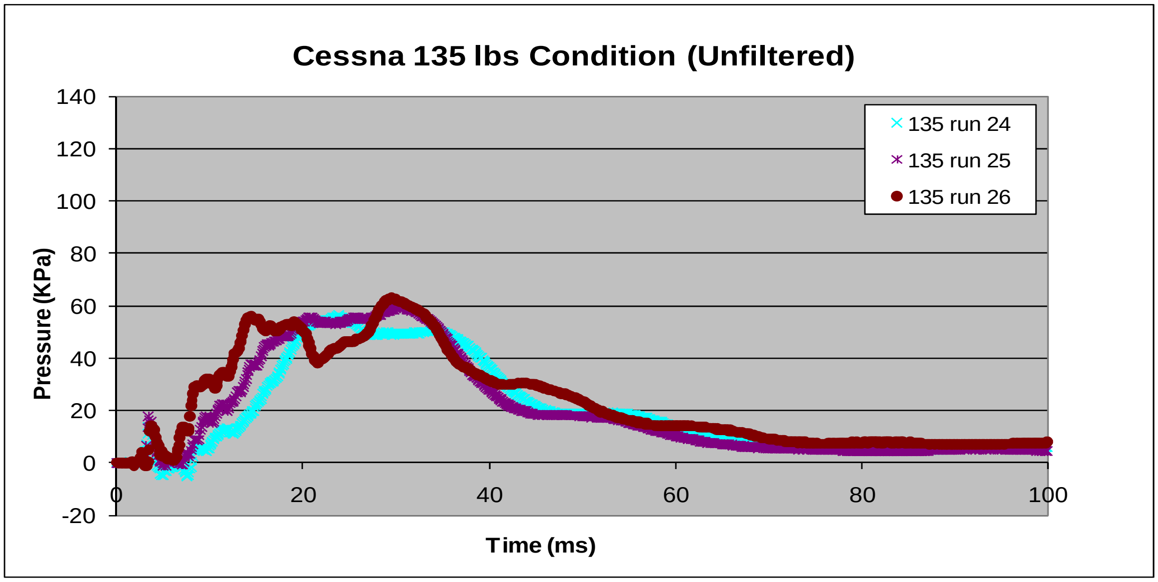


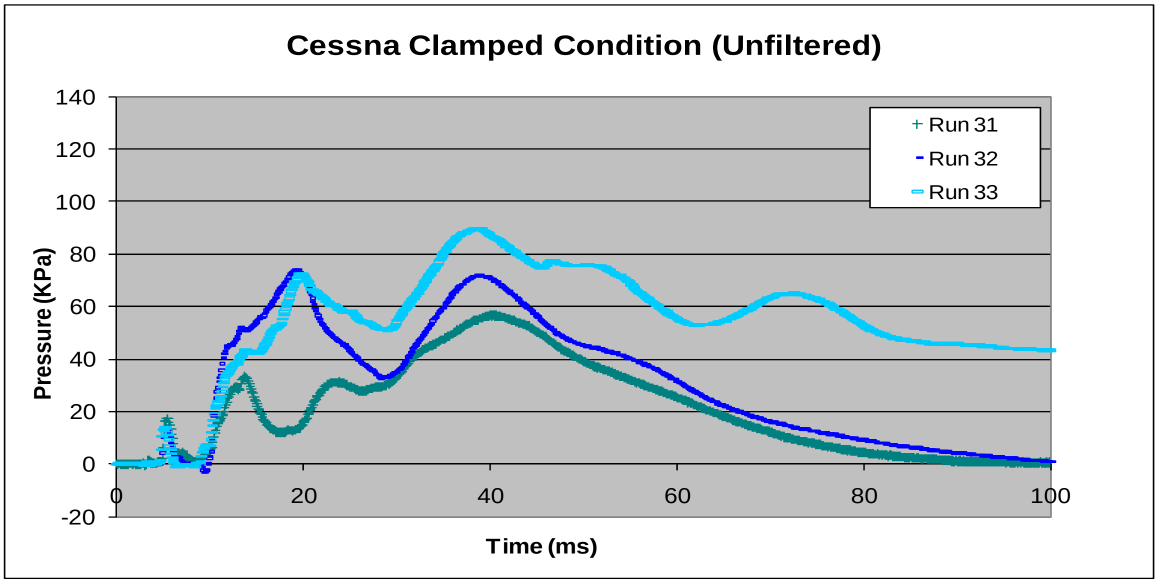

Cirrus 135 lbs Condition (Unfiltered)
Pressure (kPa)
Time (ms)
Run 17
Run 18
Run 19
140
120
100
80
60
40
20
0
-20
0
20
40
60
80
100


Cirrus Clamped Condition (Unfiltered)
Pressure (kPa)
Time (ms)
Run 29
Run 30
Run 28
140
120
100
80
60
40
20
0
-20
0
20
40
60
80
100

Cessna Deployments






Cessna Clamped Condition (Unfiltered)
Pressure (KPa)
140
120
100
80
60
40
20
0
-20
0
20
40
60
80
100
Time (ms)
Run 31
Run 32
Run 33

Appendix B. Thread fraying and peak pressure data for each trial in the study.

Trial ID	**Airbag ID**	**Bag Type**	**Condition**	**Peak Pressure (kPa)**	**Vent Hole Location**	**Threads frayed at most pronounced location**
22	22	Cessna	0 lbs	32	Top/Only	0
23	23	Cessna	0 lbs	30	Top/Only	0
1	1	Cessna	0 lbs	33	Top/Only	0
24	24	Cessna	135 lbs	56	Top/Only	0
25	25	Cessna	135 lbs	59	Top/Only	0
26	26	Cessna	135 lbs	63	Top/Only	1
31	31	Cessna	Clamped Weight	56	Top/Only	17
32	32	Cessna	Clamped Weight	71	Top/Only	3
33	33	Cessna	Clamped Weight	89	Top/Only	3
20	20	Cirrus	0 lbs	68	Top	6
					Bottom - outer layer	0
					Bottom - inner layer	0
21	21	Cirrus	0 lbs	66	Top	3
					Bottom - outer layer	0
					Bottom - inner layers	2
2	2	Cirrus	0 lbs	67	Top	0
					Bottom - outer layer	2-3
					Bottom - inner layers	2-3
14	14	Cirrus	45 lbs	118	Top	4
					Bottom - outer layer	2
					Bottom - inner layer	4-5
15	15	Cirrus	45 lbs	116	Top	2
					Bottom - outer layer	8
					Bottom - inner layer	8-9
16	16	Cirrus	45 lbs	123	Top	2
					Bottom - outer layer	0

					Bottom - inner layer	6-7
17	17	Cirrus	135 lbs	137	Top	2
					Bottom - outer layer	7-8
					Bottom - inner layer	10-11
18	18	Cirrus	135 lbs	108	Top	0
					Bottom - outer layer	6
					Bottom - inner layer	15-16
19	19	Cirrus	135 lbs	109	Top	1-2
					Bottom - outer layer	4-5
					Bottom -inner layer	9-10
28	21	Cirrus	Clamped Weight	128	Top	4-5
					Bottom - outer layer	15-16
					Bottom - inner layer	15-16
29	29	Cirrus	Clamped Weight	122	Top	12
					Bottom - outer layer	3
					Bottom - inner layer	8
30	30	Cirrus	Clamped Weight	113	Top	18
					Bottom - outer layer	4
					Bottom - inner layer	4

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